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Title: AIRPORT CONCRETE PAVEMENT WITH THE PRESET STRENGTH SAFETY LEVEL
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BACKGROUND-FIELD OF INVENTION"

This invention related to the field of design and construction of concrete pavements for airports.

BACKGROUND--DESCRIPTION OF PRIOR ART

Airport concrete pavements in the US building practice are designed usually according to Portland Cement Association Engineering Bulletin (Design of Concrete Airport Pavement, Portland Cement Association, EB050P). Strength safety of these pavements is provided by this design indirectly by limitation of working stresses. Working stress of airport pavement is determined by dividing the value of modulus of rupture of concrete (MR) by the safety factor chosen. Safety factor is in the range from 1.7 to 2.0 for aprons, taxiways, hard standings, runway ends for distance of 1,000 ft., and hangar floors as critical areas of airport. Safety factor is in the range from 1.4 to 1.7 for runways (central portions) and some high-speed exit taxiways as noncritical areas of airport. There are very wide ranges of values of safety factors and corresponding estimations of strength safety of pavement.

The preset strength safety level of airport concrete pavements should be chosen on the basis of analysis of the existing strength safety level of real structural members,

since the practice is the only criterion of strength safety. The few samplings of considerable volume of test results of underreinforced prestressed floor and roof slabs of multi-story building frames, mainly prestressed hollow-core slabs, can be used for the estimation of existing strength safety level of real structures. These slabs were designed according to the Russian building code, produced and tested at the Russian plants of precast concrete; Russian construction is based on the use of precast concrete, and the Russian building code requires regular tests of these structural members, mainly floor and roof slabs. Furthermore, the estimation of strength safety of these slabs was compared with the estimation of strength safety of columns, which is based on the test results of 111 axially loaded reinforced concrete columns of multi-story building frames produced on the Moscow plants (Sapozhnikov N. Strength Safety of Precast Reinforced Concrete and Prestressed Structural Members. State Committee of Construction of the USSR Institute of Information, Moscow, 1989, Tables 12 and 24).

According to said American building code ACI 318 (item 5.3.2.1) the required average compressive strength of concrete should exceed the specified compressive strength of this concrete f_c' by at least 25%, if coefficient of variation of this strength is assumed to be 15%. Considering the experimental value of compressive strength of concrete f_c as average, the specified compressive strength of this concrete f_c' can be estimated to be 25% less. Taking into account this difference between f_c' and f_c, the probability $P(f_r > 6\sqrt{f_c'})$ can be estimated conventionally as corresponding to strength safety index β equal to 2.88. It seems useful to compare this estimation of safety of permissible flexural stress considered as a specified flexural strength of concrete with the safety of the specified and the design compressive strength of concrete and the

yield strength of tension reinforcement.

A low level of the utilization of the flexural strength of concrete and high strength safety level of estimations of the design flexural strength of concrete are not related only to the American building practice. The analysis of the safety of the cracking resistance of prestressed flexural members designed according to the current Russian building code was provided based on the processing of the data of more than 2,000 test results of these members (Sapozhnikov N. Safety of Precast Reinforced Concrete and Prestressed Structural Members by the Second Limit State (Serviceability Limit State). State Committee of Construction of the USSR Institute of Information, Moscow, 1991, Table 4). The estimation of the safety of the cracking resistance of prestressed flexural members under service loads can be defined as a probability $P(Mcr^{test} > M_{service})$ or $P(Mcr^{test} / M_{service})$, where $M_{service}$ is the moment service force. The estimations of the safety of cracking resistance are significantly higher for samplings of test results of prestressed hollow-core and flat slabs with a developed tension zone than those for prestressed ribbed slabs and roof beams with an insignificant tension zone. The availability of the developed tension zone of prestressed members with the underestimated resources of flexural strength means the increase of the safety of cracking resistance which is not taken into account by the building code.

The main object of the present invention is to provide airport concrete pavement for aprons, taxiways, hard standings, runway ends for distance of 1,000 ft and hangar floors as critical areas of airport designed with the preset strength safety level of this pavement corresponding to strength safety index β equal at least to about 3, with the thickness less by 8-10% than that for this pavement designed according to said

Portland Cement Association Engineering Bulletin (Design of Concrete Airport Pavement, Portland Cement Association, EB 050P), reduction of thickness being achieved due to more complete utilization of flexural strength of concrete considered as random value than that provided by the current Portland Cement Association design procedure, the mix design of the concrete being carried out depending on the value of modulus of rupture (MR) required by the thickness design of pavement according to said Portland Cement Association Engineering Bulletin.

Another object of the present invention is the airport concrete pavement for runways (central portion) and some high-speed exit taxiways as noncritical areas of airport of airport designed with the preset strength safety level of this pavement corresponding to strength safety index β equal at least to about 2.5, with the thickness less by 5-10% than that for this pavement designed according to said Portland Cement Association Engineering Bulletin, reduction of thickness being achieved due to more complete utilization of flexural strength of concrete considered as random value than that provided by the current Portland Cement Association design procedure, mix design of concrete is carried out depending on the value of modulus of rupture (MR) required by the thickness design of pavement according to said Portland Cement Association Engineering Bulletin.

Still another important object of the present invention is the possibility of revaluation of strength safety and fatigue strength of existing airport pavement due to more complete utilization of flexural strength of concrete than that provided by the current Portland Cement Association design practice of utilization of this strength for increasing of allowable aircraft loads.

One more important object of present invention is the choice of the value of 90-day modulus of rupture (MR) required by the thickness design of claimed pavement according to said Portland Cement Association Engineering Bulletin in connection with the corresponding value of 28-day specified compressive strength of this concrete f_c' due to taking into account the statistical connections between flexural and compressive concrete strength, and mix design of concrete, which should be determined by this value of modulus of rupture (MR), by means of value of the specified compressive strength f_c' corresponding to this value of modulus of rupture (MR).

The main advantage of the present invention is the actual saving of 8-10% and 5-10% of total consumption of concrete for pavements of airport critical and noncritical areas, respectively, due to more complete utilization of flexural strength considered as a random value than that provided by the current Portland Cement Association design procedure.

Another important advantage of the present invention is the possibility of increasing of allowable aircraft loads of existing airport pavement due to recognition of the benefit of more complete utilization of flexural strength considered as a random value than that provided by the current Portland Cement Association design procedure.

Still another important advantage of the present invention is the possibility of design of concrete composition for 90-day flexural strength of pavement by means of the value of 28-days specified compressive strength of this concrete f_c' taking into account close statistical connections between compressive and flexural strength. Compressive strength of concrete is the common applied and well-studied characteristic of concrete, and mix design of concrete of the certain value of specified compressive

strength f_c' is a more conventional procedure than that for modulus of rupture (MR).

SUMMARY OF THE INVENTION

Airport concrete pavement for aprons, taxiways, hard standings, runway ends for distance of 1,000 ft., and hangar floors as critical areas of an airport are designed with the preset strength safety level corresponding to the value of strength safety index β equal at least to about 3. Thickness of the claimed pavement is 8-10% less than that provided by the thickness design of this pavement according to said Portland Cement Association Engineering Bulletin (Design of Concrete Airport Pavement, Portland Cement Association, EB 050P). This thickness is achieved due to more complete utilization of flexural strength of concrete considered as a random value as compared with the utilization of flexural strength of concrete provided by the current Portland Cement Association design procedure.

Thickness of the claimed pavement is determined by requirements for fatigue strength. Fatigue analysis of the claimed pavement is carried out with more complete utilization of the flexural strength of concrete than that provided by the current Portland Cement Association design procedure. More complete utilization of the flexural strength of concrete considered as a random value means the use of the values of modulus of rupture (MR) exceeding the mean value of flexural strength.

According to the invention, more complete utilization of the flexural strength of concrete considered as a random value for fatigue analysis of pavement is provided by the consecutive use of three values of 90-day modulus of rupture of concrete (MR) with

the difference of 50 psi. These three values of 90-day modulus of rupture are considered as the values of specified flexural strength of concrete and representative of distribution of density of probability of flexural strength of this concrete corresponding to the one value of 28-day specified compressive strength f_c' of this concrete. The least of these three values of modulus of rupture of concrete is the value of modulus of rupture (MR) required by thickness design of this pavement according to said Portland Cement Association Engineering Bulletin. Any of these three value of modulus of rupture of concrete (MR) can be used for fatigue analysis of the claimed pavement, if an estimation of the strength safety of this pavement designed with the use of the certain value of safety factor and this value of modulus of rupture is not less than the preset strength safety level of claimed pavement. Thickness design of the claimed pavements of airport critical areas should begin with the estimation of values of thickness of pavement corresponding to all values of safety factor in the range from 1.7 to 2.0 according to said Portland Cement Association Engineering Bulletin regardless of fatigue effect. Sufficiency of pavement of these values of thickness in terms of fatigue strength are then compared with results of fatigue analysis of the pavement.

According to said Engineering Bulletin, fatigue effect basing on general knowledge of the number of load applications expected during the pavement's life is reflected in the thickness design of pavement by the choice of a more conservative value of safety factor. According to the invention, sufficiency of pavement of values of thickness corresponding to values of safety factor in the range from 1.7 to 2.0 in terms of fatigue strength should be compared with results of fatigue analysis of the pavement. Fatigue analysis of the pavement should be carried out according to the most detailed

version of the current Portland Cement Association design procedure or with the use of other methods of fatigue analysis according to the requirements of the customer with more complete utilization of flexural strength of concrete than that provided by the current Portland Cement Association design practice of utilization of this strength. It also relates to thickness design of pavement with a determined specific forecast of traffic loads and volumes expected during the pavement's life.

Fatigue analysis is carried out beginning with the most conservative values of safety factor, if estimation of fatigue effect is based on a general knowledge of number the of load applications expected during the pavement's life. If specific forecasts of traffic loads and volumes have been determined, design procedure should begin from the least value of safety factor in this range. A minimum value of thickness of pavement of airport critical areas designed with the use of the value of safety factor in the range from 1.7 to 2.0 with the results of fatigue analysis corresponding to requirements of fatigue analysis is considered as acceptable.

Airport concrete pavement for runways (central portion) and some high-speed exit taxiways as noncritical areas of airport are designed with the preset strength safety level corresponding to a value of strength safety index β equal at least to about 2.5 has thickness by 5-10% less than that provided by thickness design of this pavement according to said Portland Cement Association Engineering Bulletin (Design of Concrete Airport Pavement, Portland Cement Association, EB 050P). It is achieved due to more complete utilization of flexural strength of concrete considered as a random value for fatigue analysis of pavement than that provided by the Portland Cement Association design practice of utilization of this strength.

Thickness design procedure of pavement of noncritical airport areas is the same as for pavement of critical areas. It should be provided with the values of safety factor in the range from 1.5 to 1.7 and required strength safety level correspond to values of strength safety index β equal at least to 2.5. Fatigue analysis of pavement with more complete utilization of flexural strength of concrete than that provided by the current Portland Cement Association design procedure is carried out according to the most detailed version of the current Portland Cement Association design procedure or with the use of other methods of fatigue analysis according to the requirements of the customer.

Airport concrete pavement for aprons, taxiways, hard standings, runway ends for distance of 1,000 ft., and hangar floors as critical areas of airport is designed according to the invention with the preset strength safety level corresponding to strength safety index β equal at least about to 3. This estimation of strength safety is considered as required strength and criterion of sufficiency of the claimed pavement in terms of strength safety. Thickness of pavement is determined by the results of fatigue analysis of pavement. Thickness design of pavement is carried out in the framework of said Portland Cement Association Engineering Bulletin (Design of Concrete Airport Pavement, Portland Cement Association, EB 050P) with the use of values of safety factor in the range from 1.7 to 2.0. Thickness design procedure of this pavement provides more complete utilization of 90-day flexural strength of concrete considered as a random value than that provided by the current Portland Cement Association design procedure. As a result, thickness of the claimed pavement is less by 8-10% as compared with the thickness of this pavement designed according to said Engineering

Bulletin EB 050P. The mix design of concrete for the above-described pavement is determined by the value of 90-day modulus of rupture (MR) required by thickness design of this pavement according to said Engineering Bulletin.

More complete utilization of flexural strength of concrete means the carrying out of thickness design of pavement with the use of values of modulus of rupture exceeding values required according to the current Portland Cement Association design procedure. Increase of value of modulus of rupture means a possibility of reduction of thickness of pavement. Efficiency of more complete utilization of flexural strength of concrete depends on the preset strength safety of pavement as a required strength safety level of this pavement. Since thickness of pavement is determined by the requirements for fatigue strength, sufficiency of reduced thickness of pavement should be checked by results of fatigue analysis of pavement. There are a few known methods of fatigue analysis of pavement. The most applicable of these methods is selected by the customer of construction (state Departments of Transportation, US Army, etc.).

According to said American building code ACI 318, the required average compressive strength of concrete f"cr has to exceed the specified compressive strength f_c' at least by 1.34**s**(f_c), where **s** (f_c) is the standard deviation of this strength. Based on the value of coefficient of variation of concrete compressive strength equal to 15%, this excess can be estimated as 25% of the value of the specified compressive strength f_c'. The required average strength of concrete fcr can be considered as a mean value of this strength f_c. This requirement of American building code ACI 318 allows the estimation of the mean value of the compressive strength of concrete depending on the value of the specified compressive strength f_c'.

Like the strength of any structural material, the flexural strength of concrete should be characterized by the specified and design strengths, with the design strength being estimated as a part of the specified strength. American building code ACI 318 and documents of the Portland Cement Association do not contain the definition of the specified flexural strength of concrete. According to the current procedure of thickness design of concrete pavements, the modulus of rupture (MR) can be considered as the specified flexural strength of concrete, whereas the working stress as a part of the modulus of rupture can be considered as the design flexural strength of this concrete.

Availability of statistical characteristics of 90-day flexural strength of concrete considered as stemmed from that for 28-day flexural strength of this concrete allows estimating the safety of design flexural strength of concrete. Strength safety of pavement is defined as a probability $P(f_r > MR/SF)$, where f_r is a 90-day flexural strength of concrete considered as a random value, MR/SF is working stress of concrete, MR is 90-day modulus of rupture of concrete considered as specified flexural strength, SF is safety factor of pavement in the range from 1.7 to 2.0. This value of working stress defined as a part of modulus of rupture (MR) is considered as design flexural strength of concrete. It means that strength safety of concrete pavement is equivalent to safety of design flexural strength of concrete.

As indicated earlier, more complete utilization of flexural strength of concrete considered as a random value means the use of greater values of modulus of rupture (MR) than that required by thickness design of this pavement according to said Engineering Bulletin. In so doing the mix design of concrete is determined by the value of modulus of rupture required by thickness design of this pavement according to said

Engineering Bulletin. According to the invention, the value of modulus of rupture provided by the current thickness design procedure and increased estimations of modulus of rupture are considered as representative of distribution of density of probability of flexural strength of concrete. Due to close statistical connections between compressive and flexural strength of concrete, the distribution of density of probability of flexural strength of concrete can be considered as corresponding to specified compressive strength of this concrete f_c' as well as the distribution of density of probability of compressive strength of this concrete. As a result, all mentioned estimations of modulus of rupture of this concrete as representatives of distribution of density of probability of flexural strength of concrete can be considered as corresponding to this value of specified compressive strength of concrete f_c'. In so doing the value of modulus of rupture of concrete provided by the current thickness design procedure just corresponds to the mean value of flexural strength and specified compressive strength of this concrete.

The distribution of density of probability of flexural strength of concrete can be represented by a few values of modulus of rupture (MR) considered as specified flexural strength of this concrete. Any of these values of modulus of rupture of concrete (MR) can be used for thickness design of claimed pavement with the certain value of safety factor, if estimation of strength safety of this pavement designed with the use of the certain value of safety factor and this value of modulus of rupture is not less than preset strength safety level of claimed pavement. As applied to thickness design of pavement of critical areas of airport, preset strength safety level corresponds to strength safety index β equal at least about to 3. In so doing strength safety of pavement is estimated

depending on the values of modulus of rupture and safety factor of pavement.

Thickness of the claimed pavement is determined by requirements for fatigue strength. According to said Portland Cement Association Engineering Bulletin, method of reflection of fatigue effect for thickness design procedure depends on the possibility to forecast the traffic loads and volumes expected during the pavement's life. If estimation of these factors is based on general knowledge of number of load applications expected during the pavement's life, fatigue effect should be reflected by selection of conservative value of safety factor in the range from 1.7 to 2.0. This is a valid procedure for design of most pavements, when appropriate factors are chosen to reflect future increases in the volumes, weights, and channelization of aircraft to be served. If specific forecast of traffic loads and volumes have been determined, pavement should be designed with the more detailed analysis of fatigue effect according to ~~of~~ said Engineering Bulletin.

As can be seen from the Table 2, each value of 28-day specified compressive strength of concrete f_c' corresponds to three values of 90-day specified flexural strength of concrete (MR) with the difference of 50 psi. The least of these three being the value of modulus of rupture (MR) required by the thickness design of pavement according to said Portland Cement Association Engineering Bulletin. Three estimations of strength safety of pavement in form of strength safety indexes β correspond to these three values of modulus of rupture (MR). Any value of modulus of rupture of concrete (MR) of these three can be used for fatigue analysis of claimed pavement, if strength safety of pavement designed with the use of certain value of safety factor and this value of modulus of rupture (MR) if strength safety of this pavement corresponds to strength

safety index β equal at least to about 3.

According to said Portland Cement Association Engineering Bulletin, fatigue effect basing on general knowledge of number of load applications expected during the pavement's life should be reflected by selection of conservative value of safety factor in the range from 1.7 to 2.0. According to the invention, sufficiency of pavement of thickness corresponding to the all values of safety factor in this range determined regardless of fatigue effect with more complete utilization of flexural strength of concrete should be checked by results of fatigue analysis beginning with the pavement of thickness corresponding to value of safety factor equal to 2.0. If results of fatigue analysis meet requirements of this analysis, the same procedure with consecutive use of three values of modulus of rupture (MR) should be carried out with the pavement of thickness corresponding to the value of safety factor equal to 1.9. If results of fatigue analysis meet requirements of this fatigue analysis, the same procedure with consecutive use of two values of modulus of rupture (MR) should be carried out with the thickness of pavement corresponding to value of safety factor equal to 1.8. If results of fatigue analysis of pavement of thickness corresponding to the value of safety factor equal to 1.8 meet requirements of this analysis, fatigue analysis of pavement of thickness corresponding to the value of safety factor equal to 1.7 should be carried out. This procedure should be carried out in the range of safety factor from 2.0 to 1.7 as long as results of fatigue analysis of pavement do not meet requirements of ~~of~~ the most detailed version of the current Portland Cement Association design procedure or other method of fatigue analysis applied to the thickness design of pavement..